

A review of science–policy interface for water governance in the Caspian Sea

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Abstract: Science and policy have been interlinked for decades and perform essential nexus conditions in the governing aspects of environmental scenarios. This review paper examines the present challenges in the science–policy interface in terms of water governance in the Caspian Sea and identifies effective conditions that may be used in the current context to enhance the mechanism. The evaluation of the science–policy link in the water policy of the Caspian Sea reveals a gap between knowledge producer and governance system, impeding the translation of scientific information into action. Complicated and context-dependent solutions make it challenging to establish effective science–policy processes in the Caspian Sea water governance settings. Establishing a common governing authority, implementing water and resource management regulations, and protecting the natural environment through legal frameworks are crucial steps to address these concerns and ensure sustainable development. Collaboration among coastal states is essential in environmental, economic, and social aspects of regional development. However, the lack of a comprehensive approach, coherent activities, and effective utilization of national and regional power has hindered efforts to halt the environmental degradation of the Caspian Sea. Local governments need to recognize their responsibility to protect and utilize the Caspian Sea for present and future generations, considering both environmental and human security. The interlinkage of the Caspian Sea water governance with the Organization for Economic Co-operation and Development (OECD) water governance principles offers a framework for policymakers to assess gaps and make necessary amendments to existing mechanisms. Effective science–policy interaction, engagement of diverse stakeholders, institutionalizing agreements, and addressing collective action issues are critical for successful water governance.

Keywords: resource management; Organization for Economic Co-operation and Development; water security; water governance principle; Caspian Sea

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1 Introduction

The Caspian Sea is a one-of-a-kind natural reservoir on the Earth as it is a landlocked body of water located on the border of two big portions of the Eurasia continent and is the largest inland

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reservoir on the planet (Akhmadiyeva and Abdullaev, 2019). With a sea area of $392.6 \times 10^3 \text{ km}^2$, the level is 27 m below sea level (Baltic elevation system) (Ragimova et al., 2020). The Caspian Sea has the same sea area as the Baltic Sea, i.e., $387.0 \times 10^3 \text{ km}^2$ (Yekimov et al., 2021), and is larger than the Adriatic Sea ($139.0 \times 10^3 \text{ km}^2$) (Modabberi et al., 2020). The Caspian Sea is traditionally split into three divisions by the morphological structure along with physical and geographical conditions: the northern (25%), the middle (36%), and the southern Caspian Sea (39%) (Akbari et al., 2020). The conditional border between the first and second passes through Chechen Island-Cape Tyub-Karagan and the line connecting the middle and southern Caspian Sea (Chilov Island-Cape Gan-Gulu) (Ghaffari et al., 2019). The depth of the southern basin, known as the South Caspian Depression (or Lankaran Depression), is 1025.0 m, while the average depth is 208 m (Lahijani et al., 2019). Baku is the Caspian Sea's largest port and the Absheron Peninsula's capital city. It has a total size of 2130.0 km^2 and a population of about 2.2×10^6 people (Serykh and Kostianoy, 2020). Rasht (Iran) (Haghghi et al., 2018), Makhachkala (Russia), and Astrakhan (Russia) are three other cities near the sea's coast (Yekimov et al., 2021). Other cities near the coastline also have populations ranging from 100×10^3 to 500×10^3 people (Koriche et al., 2022).

Along with the emergence of new coastal ecosystems, such as beach ridges and coastal lagoons, coastal inundation occurred to varying degrees during previous water level rise (1978), depending on the kind of coastal slopes (Barannik et al., 2004; Sapanov, 2018). The Caspian Sea level rise caused a significant economic impact. Protective precautions have been put in place in several metropolitan areas. However, the rising water level trend of the Lankaran Depression ended in 1995 (Jing et al., 2012). Since then, there has been a general downward trend, with a notable drop in 2010 due to exceptional summer drought in the Volga Basin (Lahijani et al., 2010). According to Baku gauge data, the Caspian Sea level at the end of 2021 was 1.9 m, lower than in 1995 (CASPCOM, 2022). Satellite altimetry reflects this shrinkage of the Caspian Sea, wherein a modest increase of 25.0 cm was detected between 2001 and 2005, followed by a continual reduction between 2005 and 2022 (Lahijani et al., 2023). It has further increased in the previous year, with a 30.0-cm decline between 2021 and 2022, compared with an average of 9.0 cm per year between 2005 and 2021 (Khaledian et al., 2020). This shrinkage affects coastal infrastructure, aquatic ecology, water circulation, and navigation (Haghghi et al., 2020).

While serving as home to the world's greatest sturgeon spawning grounds, the Caspian Sea region is rich in biological resources. The Caspian Sea's biological variety is minimal, but it stands out for its high endemism, with over 130 fish species and uncommon lotus fields (Mirrasooli et al., 2019; Vasilyeva et al., 2019). There are also over 100 bird species that use marsh areas for nesting and migration (Rasekh et al., 2023). The Caspian Sea is also home to the sea's only marine mammal, the unique Caspian seal (Sanaee et al., 2020). However, many Caspian species are now endangered due to climate change, pollution, habitat destruction, and overexploitation (Tasmagambetova et al., 2019; Verbitsky et al., 2019). It has a negative impact on human well-being, the social and economic sectors, and the provision of environmental services. The most common economic activity in the Caspian region is oil production, fishing, and shipping (Leroy et al., 2020). In the Caspian Sea basin, industry and agriculture are strongly developed (Akbulaev and Bayramli, 2020).

Owing to several issues in the Caspian Sea region in terms of water level decline, water pollution, and ecosystem degradation, there is a considerable gap in the scientific research conducted to abate these issues and the water governance mechanism in place (Jonson, 2001; Ghaffari et al., 2019; Modabberi et al., 2020; Yekimov et al., 2021; Koriche et al., 2022). Therefore, this paper focuses on assessing the existing issues in the science-policy interface regarding water governance in the Caspian Sea and suggests effective conditions that can be employed in the current scenario to improve the mechanism.

2 Methodology

The paper aims to understand the issues in water governance of the Caspian Sea in terms of

science and policy interlinkage. For this purpose, secondary research and reports highlighting the water governance issues in the Caspian Sea have been utilized to carry out qualitative research. Google Scholar, ResearchGate, Scopus, and Web of Science were used to find studies of the Caspian Sea, water governance, and policy as search strings with different permutations and combinations. The research period included and analyzed in this paper is 2001–2023. The relevance of this time period is to present the journey and development of water governance in terms of different treaties and policies signed for the Caspian Sea. We majorly scrutinized the studies based on (1) water security in the Caspian Sea; (2) existing issues in water governance; and (3) the gaps in the current policies and OECD water governance principles. Furthermore, we suggested that potential and feasible measures should be included in the existing governing mechanisms to reduce the disruption of the science–policy interface in the Caspian Sea by including different effective conditions in the existing scenario. Meanwhile, the potential of nature-based solutions was assessed concerning water governance of the Caspian Sea, and their relevance to reducing the gaps in science–policy interface was described.

3 Results and discussion

3.1 Environmental security in the Caspian Sea

Environmental issues in the Caspian Sea have been shaped by the economic development of the sea (Akbulaev and Bayramli, 2020), coastal regions (Modabberi et al., 2020), and watershed basins of rivers flowing into the sea (Serykh and Kostianoy, 2020). Each of these three components has its own environmental issues that often have similar implications. Pollution is the most serious environmental issue in the Caspian Sea (Modabberi et al., 2020; Behrooz et al., 2021; Hatami et al., 2022; Koriche et al., 2022). Simultaneously, an anthropogenic load on the Caspian region occurs against diverse natural (endogenous and exogenous) processes (Koriche et al., 2022). The first includes sea level variations (Serykh and Kostianoy, 2020), morpholithodynamic processes in the coastal zone (Gonikov, 2019), the occurrence of seismic events regularly (Leroy et al., 2022), storm surge phenomena (Serykh and Kostianoy, 2020), and mud volcanism (Farhadian Babadi et al., 2021). The general environmental status in the Caspian Sea basin was assessed as a precrisis towards the close of previous century, accompanied by a severe worsening of the sanitary-toxicological and fishing situations.

The Circum-Caspian region was considered as a high environmental stress region in the 1990s, characterized by the availability of roughly equal regions with acute and relatively acute environmental circumstances (Leroy et al., 2020). Other sources describe it as a region under extreme stress, owing to the combined action of negative natural and anthropogenic factors, as well as the growing threat of degradation of natural complexes in the coastal zone and ecosystems throughout the Caspian Sea (Zonn, 2005; Jafari, 2010; Yekimov et al., 2021). According to some authors, it is the first stage of an environmental disaster (Lahijani et al., 2023). The environmental focus has changed in recent years from industrial pollution (due to a decline in industrial production) to pollution caused by waste of hazardous substances due to sea level rise. Furthermore, changes in the natural environment can impact economic, political, and demographic issues that determine power geography (Huitema et al., 2009). Limitations in resource use can be interpreted as a security risk (Leroy et al., 2020). Environmental dangers (natural or human) can lead to struggle and conflict to acquire access to scarce resources (Madani, 2010). Environmental threats to national security are similar to military and economic challenges in that they weaken governments' material bases and can grow to the point of endangering governments and their institutions (Garibov, 2018).

According to the Caspian Environment Programme, the number of sturgeons caught in Iran and the former USSR (Union of Soviet Socialist Republics) countries decreased between 1929 and 1998 (Bayramov, 2020). The volatile political climate in the region can explain the ups and downs in sturgeon output. Following the Second World War, industrial restoration gradually increased, which peaked at over 28.9×10^3 t in 1977 (Guliyev, 2012; Koriche et al., 2021). Furthermore, the

demise of USSR and a lack of environmental restrictions in newly independent republics led to large-scale organized poaching, which was a major contributor to the steep drop in sturgeon capture (Bayramov, 2020). Some species are now endangered due to increased oil production, pollution, alien species invasion, habitat degradation, and poaching (Verbitsky et al., 2019; Modabberi et al., 2020; Farhadian Babadi et al., 2021; Lama et al., 2022). Creating a joint governing institutional authority, providing a legal structure for water and resource management, and protecting the natural environment are critical for eradicating environmental stress in the area.

3.1.1 Water governance in the Caspian Sea

The Soviet legacy has left intricate relationships among Central Asian states on both national and regional levels, interconnected by pre-existing water infrastructure and intrastate regulations (Mihr, 2020). During the era of USSR, water management was centralized in Moscow, and regional bodies only executed decisions. Following the demise of USSR, each independent country had to determine water-related decision-making authorities, institutions, and responsibilities, marking the emergence of the water governance paradigm in Central Asia (Bota and Nataliya, 2022). The adoption of Integrated Water Resources Management (IWRM) represented a significant milestone, involving principles such as managing water based on hydrographic boundaries and public participation (Zonn et al., 2020). While Central Asian states have encountered challenges common to Global South countries, such as limited resources and ownership of IWRM, specific issues persist in the region. Implementing IWRM has revealed limitations: water user associations struggle with self-governance, coordination between administrative and hydrographic management scales is challenging, and numerous institutions with overlapping functions exist (Zonn et al., 2020).

The current trajectory of water governance concerning the Caspian Sea can be traced by examining the interstate pacts, which fall into two main categories: delineation of the seabed and safeguarding the environment (Akhmadiyeva and Abdullaev, 2019; Fig. 1). Nearly all agreements related to seabed delineation have been bilateral in nature and have primarily aimed at facilitating the extraction of hydrocarbon resources from beneath the seabed (Akhmadiyeva and Abdullaev, 2019; Koriche et al., 2022). Nevertheless, the lack of agreement regarding the legal standing and conflicts over ownership of specific oil and gas fields has hindered the realization of extensive offshore projects. The uneven distribution of hydrocarbon reserves in offshore areas has been the primary factor contributing to dispute over legal status among the five littoral states of the Caspian Sea (Azimi et al., 2020; Ivanov et al., 2020). Additionally, the littoral states of the Caspian Sea have been embroiled in disputes over legal status and resource delimitation, causing a pause in environmental negotiations for over a decade. None of the five states have taken responsibility for environmental degradation or the depletion of natural resources and biodiversity, instead prioritizing extensive hydrocarbon extraction and using only limited environmentally friendly technologies (Bayramov, 2020). The Tehran Convention, signed in November 2003 by all littoral states after years of no agreements, marks the first legally binding regional pact for the protection of the Caspian Sea's marine ecosystem. It includes three protocols and sets out requirements and institutional mechanisms for preserving and sustainably developing the marine environment (Akhmadiyeva and Abdullaev, 2019). However, its practical implementation has been delayed due to the inability of the Caspian states to reach consensus on various protocols related to biodiversity conservation, pollution, oil incident response, and environmental impact assessment. Furthermore, the Aktau Protocol, in force since July 2016, mandates littoral states to prepare for and respond to oil contamination incidents (Seyrafi, 2020). The Moscow and Ashgabat Protocols, ratified by some countries, are still pending enforcement (Akhmadiyeva and Abdullaev, 2019). The Tehran Convention Secretariat, managed by United Nations Environment Programme (UNEP), is the sole regional institution overseeing the protection of the Caspian Sea's marine environment, assisting the states in adhering to the Convention and its Protocols (Garibov, 2018). While the newly established Convention on the Legal Status signifies progress toward sustainable water governance of the Caspian Sea, its emphasis largely centers on regional security,

with limited attention given to environmental concerns, mostly pertaining to scientific research on hydrobiological resources (Amiraslani and Dragovich, 2023).

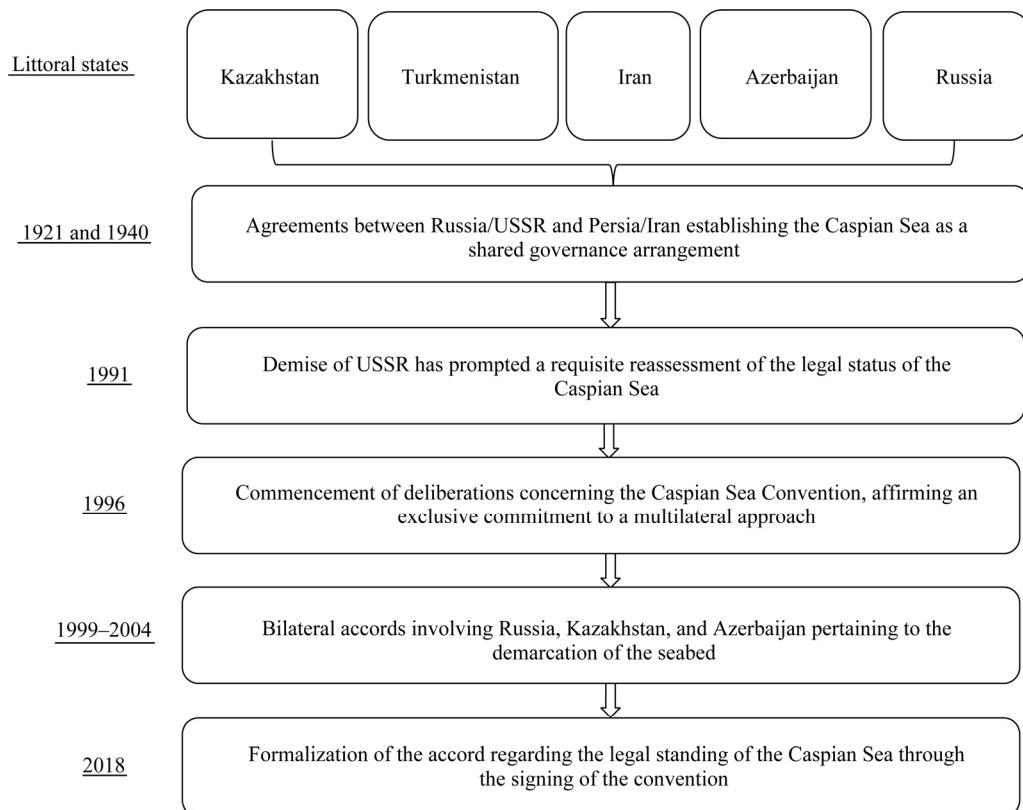


Fig. 1 Framework of political convention of the Caspian Sea. USSR, Union of Soviet Socialist Republics.

3.1.2 Unsolved issues in the Caspian Sea

Despite the latest treaty signed by the leaders of the five littoral states to the Caspian Sea–Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan on 12 August, 2018, there are a number of unsolved issues such as: (1) treaty grants sovereign and exclusive rights to littoral states for exploiting natural resources in their seabed sectors; (2) northern Caspian model extends to southern Caspian, allowing Azerbaijan, Iran, and Turkmenistan to establish bilateral agreements for sector delimitation; (3) Iran compromises by accepting this disposition, abandoning its demand for a condominium approach, and resulting in a smaller share of energy resources; (4) delimitation of southern Caspian seabed is not agreed upon due to refusal of Iranian President to the median principle; (5) Iran's claims to the Araz-Alov-Sharg oil and gas field challenges historical tensions between Iran and Azerbaijan over field's ownership; (6) treaty resolves only 30% of Caspian delimitation issues, signaling Iran's limited willingness to compromise further; (7) Turkmenistan and Azerbaijan contest Serdar/Kapaz oil field efforts to unlock the Trans-Caspian Pipeline (TCP); (8) treaty potentially revives border negotiations between Turkmenistan and Azerbaijan; (9) Turkmenistan's vast gas reserves face economic challenges, prompting infrastructure development for increased domestic production and western gas exports; (10) Turkmenistan's gas exports to Russia and Iran cease due to pricing disputes and resumption of exports to Russia; and (11) Turkmenistan exports $30 \times 10^{12} \text{ m}^3$ of gas to China via the Central Asia–China pipeline, facing pricing challenges and limited demand (Akbari et al., 2020; Bayramov, 2020; Pietkiewicz, 2021; Amiraslani and Dragovich, 2023). Amongst these issues, exploitation of natural resources in seabed sectors is one of the major water governance, but causing a disruption in science–policy interface in the Caspian Sea.

3.2 Existing gaps in science–policy interface for water governance

The environmental stress in the Caspian Sea may worsen as the economic potential grows due to hydrocarbon extraction, the construction of new seaports, the rehabilitation of existing ones, the revival of merchant tanker fleet, the enhancement of navy component, and the construction of oil and gas pipelines (Yekimov et al., 2021).

The Caspian Sea, influenced by geological, hydroclimatic, anthropogenic, and spatial factors, has undergone significant environmental changes in the last decade (Nadim et al., 2006; Dero et al., 2020). These changes have been influencing climate variations and shifts in sea levels within the Caspian Sea, particularly along its coastal regions. Fluctuations in water levels have been pronounced, with notable shifts in the 20th century, including rapid declines from 1931 to 1940 and subsequent rises between 1978 and 1995. Since 1996, there has been a decline, with a significant drop from 2006 to 2015 and stabilization in 2016–2017 (Modabberi et al., 2020; Lahijani et al., 2023). These water level changes result from a combination of factors, including evaporation due to elevated temperatures and alterations in precipitation and river discharge. Prolonged trends could lead to the disappearance of the northern Caspian Sea and surrounding areas within 75 a, while heightened salinity threatens biodiversity, soils, infrastructure, and public health (Akbari et al., 2020; Lahijani et al., 2023). Escalating air and water temperatures are also concerning, impacting ice cover, water circulation, and chemical and biological processes. Global warming has led to temperature increases of about 0.7°C–0.8°C in air and 0.4°C–0.5°C in surface water during the latter part of the 20th century (Dero et al., 2020). The region is vulnerable to extreme weather patterns attributed to climate change, resulting in economic losses from floods, agriculture impacts, and population displacement. Flash floods, triggered by heavy rainfall and poor land use practices, exacerbate challenges (Koriche et al., 2022). Desertification affects over half of the Azeri coastline and interior Iran. In summary, the Caspian Sea region faces a complex array of environmental issues, including water level fluctuations, rising temperatures, extreme weather events, and desertification. These challenges have broad repercussions, affecting various sectors, livelihoods, and ecosystems across the area. The main contributors to these changes include the direct drivers, i.e., habitat deterioration, population expansion, tourism, fishing, and agriculture, and indirect drivers, i.e., urban development, oil and gas operations, unauthorized fishing, agricultural practices, etc. (Dero et al., 2020; Koriche et al., 2022).

Additionally, the risk of harmful effects of hydrocarbon deposit development in the bottom and coastal regions of the Caspian Sea is especially evident in the shallow-water northern Caspian, which is exclusively crucial for the development of unique commercial biological resources while also serving as a nature-reserve zone (Azimi et al., 2020; Ivanov et al., 2020). Table 1 highlights the major gaps in the Caspian Sea's science–policy interface for water governance.

Due to the importance of environmental protection in sustainable development, the states must include sustainable development goals in their regulations, laws, and policies (Madani, 2010). In fact, if environmental rules are internalized as a part of the domestic legal system, they will become more prominent and respected (Cook and Bakker, 2012). The existence of common interests and problems in the region has made coastal states' cooperation in all fields inevitable. Indeed, this cooperation is not limited to environmental cooperation, and the need for sustainable regional development has inevitably led to economic and social cooperation (Jonson, 2001; Nouri et al., 2008; Alipour et al., 2017). The destruction of the Caspian Sea ecosystem can be shaped as soon as possible, but it is unlikely to recover, and restoring it certainly will be very timely if it is not impossible in some areas (Barannik et al., 2004; Leroy et al., 2020; Modabberi et al., 2020; Ragimova et al., 2020; Koriche et al., 2022; Lahijani et al., 2023). There will be no alternative in some cases, including the extinction and destruction of rare species (for example, the genetic reserves of sturgeons of the Caspian Sea) (Tasmagambetova et al., 2019; Verbitsky et al., 2019). Governmental measures alone cannot ensure sustainable conservation and exploitation of the Caspian Sea. There has been a failure to stop the environmental degradation of the Caspian Sea

due to the lack of a comprehensive approach and coherent activities and a lack of utilization of national and regional power (Yekimov et al., 2021). The severity of pollution and destruction in the Caspian region makes it impossible to rely on issues such as the uncertainty of the agreed legal regime on the Caspian Sea (Mirzaei et al., 2017; Sapanov, 2018; Akhmadiyeva and Abdullaev, 2019).

Table 1 Gaps in science–policy interface for water governance in the Caspian Sea

Gap	Description in terms of water governance	Reference
Environmental stress factors	Severe contamination by substantial amounts of heavy metals because of sewage discharge Pollution from organic compounds due to the influx of agricultural and industrial discharges Eutrophication Water level fluctuations Hydrocarbon extraction Construction of new seaports and rehabilitation of existing ones Revival of merchant tanker fleet Enhancement of navy component Construction of oil and gas pipelines	Akhmadiyeva and Abdullaev (2019); Akbulaev and Bayramli (2020); Ghayebzadeh et al. (2020); Farhadian Babadi et al. (2021); Yekimov et al. (2021); Mokarram et al. (2023); Modabberi et al. (2020); Dero et al. (2020)
Challenges in conservation	Governmental measures alone cannot ensure sustainable conservation and exploitation of the Caspian Sea Lack of a comprehensive approach and coherent activities, as well as a lack of utilization of national and regional power Severity of pollution and destruction in the Caspian region is so great that it is not possible to rely on the agreed legal regime on the Caspian Sea	Koriche et al. (2021); Ghafourian and Sadeghzadeh (2022); Hatami et al. (2022); Zakeri et al. (2022)
Responsibility of coastal governments	Recognizing the right of present generation and future generations to protect the Caspian Sea Environmental characteristics of the Caspian Sea also have potential impacts on regional security	Bayramov (2020); Pietkiewicz (2021); Ghafourian and Sadeghzadeh (2022)
Unresolved disputes	Lack of cooperation mechanism in the latest treaty Communication barrier and hindrance in decision making	Pietkiewicz (2021)
Human security implications	Sharp increase in unemployment rate of the fishing industry due to the reduction of fish stocks Shipping companies are affected	Yekimov et al. (2021); Koriche et al. (2022); Rasekhi et al. (2023)
Challenges in resource division	Oil and gas resources of the Caspian Sea have caused each country to have different positions regarding the legal regime of the sea, which does not have necessary consistency	Akbulaev and Bayramli (2020); Pietkiewicz (2021); Hatami et al. (2022)

Negotiations and diplomatic agreements as well as overcoming the existing political bottlenecks, are processes that require time to resolve while protection of the Caspian Sea and the rights of the interested parties are not subject to the agreement of the legal regime (Bayramov, 2020; Pietkiewicz, 2021). Caspian ecosystems and the lives of their organisms do not depend on political borders and diplomatic agreements, and their right to life cannot be subject to the agreement of the coastal states (Tasmagambetova et al., 2019). Therefore, coastal governments and leaders of these countries should feel responsible for recognizing the right of the present generation and future generations to protect and exploit the Caspian Sea on their shoulders and realize their responsibility. The Caspian Sea's environmental characteristics also potentially impact regional security (Ragimova et al., 2020). Therefore, all coastal states must consider the stability of this water zone by utilizing their maximum national power while developing regional cooperation and utilizing the capacities of other international actors, including international organizations (Nouri et al., 2008; Pahl-Wostl et al., 2013; Sapanov, 2018). In this regard, it is necessary to protect this water land by relying on intellectual and scientific principles, including the principles of prevention and the possible use of all legal and executive capacities.

A comprehensive look at the issue of environmental security directly connects with the issue of human security (Pietkiewicz, 2021). Concerning the Caspian Sea, this can be seen in terms of the

sharp increase in the unemployment rate of the fishing industry due to the reduction of fish stocks; subsequently, shipping companies are affected (Akbulaev and Bayramli, 2020). Further, the Caspian region has become increasingly crucial regarding regional and global environmental security. The new geopolitical and economic requirements of the region (after the demise of USSR) have created a mixture of competition, cooperation, and ideological, economic, political, and legal controversy (Gonikov, 2019; Leroy et al., 2020; Koriche et al., 2022). The serious debate is how the Caspian Sea and its resources are divided among coastal governments. The oil and gas resources of the Caspian Sea have caused each country to have different positions regarding the sea's legal regime, which does not have the necessary consistency (Pietkiewicz, 2021).

3.3 Linking water governance of the Caspian Sea to the OECD principles

The OECD is a unique platform where 37 democratic nations with market-driven economies collaborate to establish policy standards that promote sustainable economic growth (Blind, 2012). It serves as a space for governments to compare experiences, address shared challenges, identify best practices, and set high standards for economic policies. The Water Governance Initiative, part of the OECD Water Governance Programme, was created in 2013 as a multi-stakeholder platform involving public, private, and non-profit sectors (Akhmouch and Correia, 2016). This initiative convenes every six months in a Policy Forum to address water governance gaps and pursue goals established by the 6th World Water Forum, in which the OECD played a key role (Akhmouch and Correia, 2016). The resulting OECD principles on water governance were developed recognizing that water challenges require tailored solutions, embracing the diversity of legal, administrative, and organizational systems within and across countries (OECD, 2015). These principles acknowledge the contextual nature of governance, the need to adapt water policies to specific resources and locations, and the requirement for governance responses to evolve alongside changing circumstances (OECD, 2015; Akhmouch and Correia, 2016). Therefore, to promote uniformity in the concept of water governance and acquire water security at the global level, the OECD has devised water governance principles (Akhmouch and Correia, 2016; Woodhouse and Muller, 2017).

However, in the existing scenario, Caspian Sea governance is facing geopolitical issues at the regional and national policy level, so the standardization of the principles is pending therein (Orazgaliyev and Araral, 2019; Bayramov, 2020). The following subsection describes the possible linkage of the existing water governance at the Caspian Sea and the principles provided by the OECD (Table 2).

3.4 Conditions for effective science–policy interface in the Caspian Sea

Majorly the disruptions in science–policy interaction occur due to gaps in the inception and implementation of policy frameworks. To attain the most effective stage of the science and policy cascade, it is relevant to test the 'science-to-policy hypothesis' formulated in the initial research steps (Armitage et al., 2015). This hypothesis is objective about the outcome of the policy pilot testing and is imperative to be qualified at each step in terms of its acceptance and functioning (Brugnach et al., 2007; Willems and de Lange, 2007).

To employ effective coordination of science and policy aspects in water governance, multiple conditions are relevant (Fig. 2). In addition to the mandatory factors to be incorporated in the existing mechanism, nature-based solutions also have an essential and crucial role to play in improving the said balance, and hence, the following sub-sections also analyze the potential and feasibility of nature-based solutions to provide an overall framework of the improvement measures.

3.4.1 Scientific approach towards policy formulation

Perspectives of science–policy processes as linear relationships often ignore the complicated realities of decision-making (McNie, 2007; Vogel et al., 2007). A diverse set of stakeholders is now participating in water decision-making, and the status and function of scientists in

Table 2 Interlinkage of the OECD principles with water governance of the Caspian Sea

OECD principle	Category	Existing gap (Caspian Sea)
Allocation and identification of defined roles regarding water policy (formulation, implementation, management, regulation, and coordination)	Politics	Conflicts of interest and rivalry for influence among state actors have resulted from the shift of power and influence in the region
Management of water at suitable levels within basin governance integration	Politics	Lack of definition of exact location of the boundaries or the specific allocation of territorial waters, common maritime space, seabed, and sub-soil to each state
Support coherence in policy through efficient cross-sectoral coordination, particularly between water and environmental policies	Governance	Water governance in the Caspian Sea lacks adherence to the concept of integrated water resource management that leads to the deterioration of water and associated ecosystem
Adaptation of the level of ability of the accountable authorities to the degree of complexity of the water concerns to be addressed, as well as the set of competences required to carry out their responsibilities	Governance	Absence of robust regional cooperation and accord on water and environmental concerns continues to hinder and deter states from safeguarding the sea water and surrounding ecosystem
Production, refurbishment, and timely dissemination of the consistent, comparable, and policy-relevant water, and water-related statistics and information for use in guiding, assessing, and improving water policy	Governance and research	Hydro-social cycle displays a gap and there is a requirement of technical system platform to push the Caspian Sea region to the reflexive modernity
Ensuring mobilization of water finances and allocation of financial resources in an efficient way via governance arrangements	Governance	Requirement of a model that will define sources of investment in desirable economic projects, youth projects, and assistance in water security
In the public interest, ensuring that competent water management regulatory regimes are successfully implemented and enforced	Governance and society	Unresolved issue in the latest treaty causing vast gas reserves to face economic challenges, prompting infrastructure development for increased domestic production and western gas exports; and exploitation of natural resources in seabed sectors
Encourage responsible authorities, levels of government, and key stakeholders to adopt and implement innovative water governance methods	Politics	Lack of coordination among Central Asian governments reduce their ability to tackle external water management problem
Integrity and transparency standards should be consolidated into water policies, institutions, and governance frameworks to increase accountability and confidence in decision-making	Governance and research	Lack of consensus in negotiating the protocols on environmental impact assessment, oil incidents, water pollution, and biodiversity conservation
Encourage stakeholder participation to make educated and outcome-oriented contributions to water policy creation and implementation	Society	Due to political issues on the boundary conditions of the sea, citizen science projects are stagnated
Encourage the development of water governance frameworks that aid in the management of trade-offs between water users	Governance and economy	Lack of coastal authority that defines the water share amongst the states in bilateral and multilateral agreements
Encourage regular monitoring and evaluation of water policy and governance and display the results in public domain	Research and society	Requirement of a stand-alone body to monitor the impact of paradigm shift in the water governance in the Caspian Sea region and disseminate transparent analysis in public domain

Note: OECD, Organization for Economic Co-operation and Development. The OECD principles are referenced from <https://www.oecd.org/cfe/regionaldevelopment/OECD-Principles-on-Water-Governance-en.pdf>.

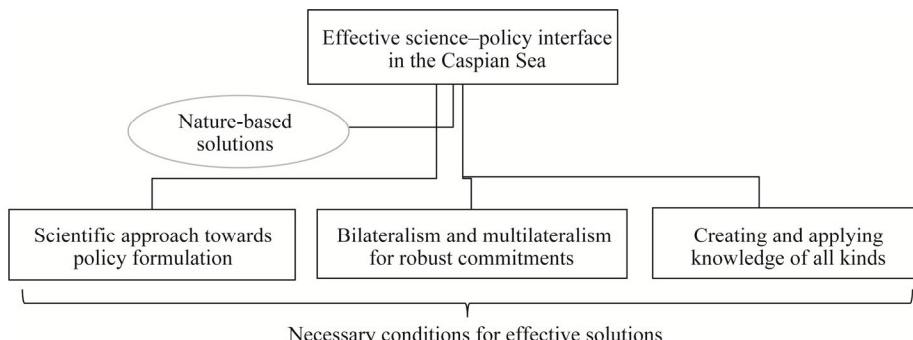


Fig. 2 Conditions for effective science–policy interface in the Caspian Sea

policy-making processes have shifted (Mirumachi et al., 2010). This movement is part of a larger societal transition toward increased public scepticism of science and the democratization of information (McNie, 2007). Scientists working in these settings require government and institutional support and openness to better convey their knowledge to a wide range of audiences. It is also necessary to provide rewards, incentives, and requirements for scientists to participate in more open, collaborative, and learning-centered processes. A worry that scientific knowledge is not 'upgraded' above or appreciated to the disadvantage of traditional knowledge and traditional knowledge bearers is implicit in this transition to more effectively exchange and transmit knowledge (Lejano and Ingram, 2009).

Environmental measures taken unilaterally by only one of the states will not have the desired effect but will instead contribute to an increase in hydrocarbon production in countries with less stringent environmental legislation, resulting in an increase in the volume of harmful substance emissions into the Caspian Sea (Jafari, 2010; Lahijani et al., 2019; Bayramov, 2020; Ivanov et al., 2020; Farhadian Babadi et al., 2021). Furthermore, increased participation by a broader range of non-governmental sectors in the Caspian Sea region can result in greater legitimacy, more effective and equitable resource allocation, a better cost-benefit ratio, enhanced access to a wide range of knowledge and expertise, and greater acceptance and success in policy implementation (Akhmadiyeva and Abdullaev, 2019; Ghafourian and Sadeghzadeh, 2022).

Utilizing IOT (Internet of Things) to understand the relationship between science and policy performance in water governance is imperative (Armitage et al., 2015; Katayani and Barua, 2016). Missing gaps and overlaps can be studied using post-processing and analysis of the relationships between policy implementation tasks, guidance, experiences, and tools (Woodhouse and Muller, 2017).

3.4.2 Bilateralism and multilateralism for robust commitments

Governance of water security challenges in the Caspian Sea necessitates collaborative efforts, including shared fact-finding, from which trust-building occurs at the start of science–policy cooperation (Yekimov et al., 2021). To reconcile the conflicting perspectives, people argued the legal status of the Caspian Sea for 22 a (Akhmadiyeva and Abdullaev, 2019). The presidents of the five littoral republics signed the "Convention on the Legal Status of the Caspian Sea" on 12 August, 2018, in Aktau, Kazakhstan (Pietkiewicz, 2021). While signing the agreement was greeted with much optimism in the region and beyond as the long-awaited solution to the problem, it also left caveats in the final settlement of the major maritime disputes (Löwisch and Eschment, 2022). Moreover, the issues that persist are the demarcation of highly problematic sectorial seabed borders in the southern Caspian Sea (Arne et al., 2021), followed by clarification of ownership of the disputed fields (Bayramov, 2020), and the construction of underwater trans-Caspian pipelines (Cutler, 2019).

The bilateral and multilateral agreements made by Russia, Azerbaijan, and Kazakhstan in 1997, 1998, and 2001, respectively, and by Turkmenistan and Kazakhstan in 2014, effectively eliminated any disagreement about northern Caspian seabed borders (Orazgaliyev and Araral, 2019). However, the major disputes in the sea's southern part still disturb the governing mechanism. As a result, further negotiations will most likely take place outside of the common Caspian summits in bilateral or trilateral talks between Baku, Tehran, and Ashgabat (Orazgaliyev and Araral, 2019; Bayramov, 2020).

Establishing relationship to overcome misconceptions about the distinct logic of science and policy takes time and produces few tangible results in the early stages (Armitage et al., 2015; Woodhouse and Muller, 2017). Investing time upfront in shared problem framing and engaging policymakers and other players, such as communities and industrial partners, in the knowledge generation process, rather than considering them as passive end users helps to ensure that high initial transaction costs produce long-term returns (Huitema et al., 2009; Pahl-Wostl et al., 2013). Early time and resource commitments are required to develop a shared understanding of fundamental problems as well as the larger political and social circumstances that frame water

decisions (Madani, 2021). Furthermore, the states of the Caspian Sea need to institutionalize the achievements in the agreements via robust legislation (Leroy et al., 2020).

3.4.3 Creating and applying knowledge of all kinds

All water management must balance different goals and competing interests. Because the hydrological cycle is interrelated, one user's withdrawals from or discharges into a shared water source can affect the quantity or quality of resources accessible to others (Pahl-Wostl et al., 2013). As a result, water governance raises intrinsic barriers to collaborative action (Cook and Bakker, 2012). Collective action issues occur when actors in interdependent systems act autonomously, rationally pursuing their own goals while imposing externalities on other participants and attaining lower joint value than mutually beneficial outcomes that may have been attained (Johannessen et al., 2019; Pahl-wostl, 2019).

Water governance today must rely on knowledge in all its forms. This knowledge is owned, formulated, and conveyed by a wide range of actors at all levels of government, both inside and outside (Jiménez et al., 2020; Pahl-wostl et al., 2020). Because of varied, potentially contradicting, and often incompatible ways of knowing (e.g., between scientific and traditional knowledge systems), integrating different types of knowledge in water decision-making can be highly difficult (Huitema et al., 2009; Pahl-Wostl et al., 2013; Mirzaei et al., 2017). Being transparent about the use of diverse types of knowledge is vital for valid decision-making processes, as is a commitment to 'knowledge co-production' procedures that bring together a variety of data sources and types to define and address problems (Brugnach et al., 2007; Madani, 2021). A working knowledge co-production process is not meant to resolve situations in which knowledge and comprehension of water conditions are incompatible (Katyaini and Barua, 2016; Yekimov et al., 2021).

The main sources of pollution in the Caspian natural environment are on land and offshore, oil transportation via sea, navigation over both rivers, operation of oil and gas wells, municipal-domestic wastewaters, discharge of untreated industrial and agricultural wastewaters, wash off with river flow, and transborder atmospheric and water transfer of pollutants from other regions (Barannik et al., 2004; Zonn, 2005; Nadim et al., 2006; Jafari, 2010; Haghghi and Kløve, 2018; Dero et al., 2020; Ragimova et al., 2020; Yekimov et al., 2021; Ghafourian and Sadeghzadeh, 2022). Furthermore, the southern and middle Caspian regions are vulnerable to significant geodynamic hazards, including seismicity (Leroy et al., 2022). Therefore, sharing the water quality issues and their potential remedial measures are relevant and intrinsic to improvising water governance and science–policy interface (Nadim et al., 2006; Pahl-wostl, 2019; Yekimov et al., 2021).

3.4.4 Potential of nature-based solutions to improve science–policy interface in the Caspian Sea

Coastal landscape planning ensures that human activities are properly allocated while conserving and improving landscape characteristics. Since the Caspian Sea is under the jurisdiction of multiple parties and is a base of conflict of interest, the policy solutions should be based on the notion that assessing coastal landscape characteristics, zoning, and recognizing sensitive coastal regions would aid in the appropriate allocation of human use and activities in the development of sustainable tourism (Alipour et al., 2017; Akbulaev and Bayramli, 2020; Ghafourian and Sadeghzadeh, 2022). In such a large and dependable water body, the tourism sector plays an essential role in its economic and sustainable development under each state in the Caspian Sea region. Furthermore, fostering nature-based solutions as an alternative to economic development in the sea will provide a supportive statement for the social ties among the states. Efforts focused on enhancing the overall water condition, rather than targeting specific metrics, and held greater promise for achievement, especially when they involve directly rejuvenating natural ecosystems through the management of underlying pressures, commonly known as nature-based approaches or solutions (Boano et al., 2020). These solutions can be employed as citizen science projects that can be piloted and scaled up as per their performance. Nature-based solutions play a dual role in managing flood and drought impacts by supporting stormwater control and water supply systems

simultaneously (Bunclark and Hernández, 2022). They are crucial for preserving the natural hydrological cycle, especially as urban areas expand and surfaces become more impermeable. They not only maintain the balance between evapotranspiration and rainfall but also mitigate urban heat effects and facilitate green space growth using local water resources (Ferreira et al., 2023). Furthermore, they offer effective purification of diverse water sources such as greywater, rainwater, sewer overflow, and wastewater for various uses, yielding multiple additional advantages (Albert et al., 2021). Beyond water treatment, they can retain stormwater, facilitate food production through irrigation, and conserve energy (Babí Almenar et al., 2021). Nature-based solutions can be applied to address the science–policy interface issue in the Caspian Sea region via planning, piloting, and replicating the impact to a larger geographical coverage (Fig. 3). While nature-based solutions are not foreseen as a mandatory aspect for improving the water governance in the region, its feature of stabilizing the water ecosystem activities drives its potential to be included in the cascade of improving science–policy interface.

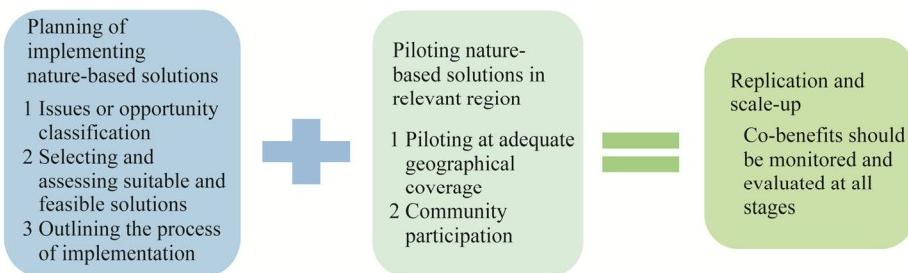


Fig. 3 Inclusion of nature-based solutions in water governance of the Caspian Sea

These nature-based solutions are also appropriate for combating the water pollution issue in the Caspian Sea (Nesshöver et al., 2017; Raymond et al., 2017; Cousins, 2021). Since major water pollution issue in the Caspian Sea region is caused due to oil spilling cases, nature-based solutions can be deployed at regional and national scales to control and mitigate these problems with minimum damage (as caused in case of grey infrastructure) (Zingraff-Hamed et al., 2017; World Water Assessment Programme, 2018; Babí Almenar et al., 2021). Seasonal and short-term Caspian water level changes occur because of meteorological forcing (Lahijani et al., 2010, 2023), tidal effects (Medvedev et al., 2017), river flooding (van Baak et al., 2019), and steric shifts. Long-term water level variations are mostly related to the water budget, which includes two critical components: riverine input and evaporation from the water surface (Soheil et al., 2018; Azizpour and Ghaffari, 2023). Therefore, another problem that can be addressed through these solutions is water level changes and flood events that are otherwise bound to cause hazardous impacts on the coastal communities (Frantzeskaki et al., 2019; Senes et al., 2021; Strack et al., 2022).

4 Conclusions

An evaluation of the scientific–policy link strength in the water policy of the Caspian Sea finds a knowledge-governance gap. It refers to the communication gap between knowledge makers and the governance system and serves as a barrier to converting scientific information into action. Furthermore, due to complex and context-based solutions, there is a lack of blueprints for good science–policy processes in the water governance settings of the Caspian Sea. The environmental security in the Caspian Sea is shaped by the economic development of the regions, coastal water, and watershed draining into the sea. Pollution is the most serious problem affecting the region, with both natural and human-induced processes contributing to ecosystem degradation. Seismic events, sea level variations, coastal zone changes, storm surges, and mud volcanism further compound the environmental challenges. In due course of time, the environmental situation has

shifted from industrial pollution to hazardous waste disposal due to rising sea levels. These changes in the natural environment impact the ecosystem and have consequences for economic, political, and demographic factors that shape power dynamics. Environmental threats can lead to conflicts over scarce resources and pose a severe risk to national security. Establishing a joint governing authority, implementing water and resource management regulations, and protecting natural environment through legal frameworks are crucial to address these environmental concerns effectively.

States must incorporate environmental protection goals into their regulations, laws, and policies to ensure sustainable development. Cooperation among coastal states is inevitable, not only in environmental matters but also in economic and social aspects of regional development. Conservation and restoration of the ecosystem in the Caspian Sea are challenging and may not be possible in some areas, leading to the extinction and destruction of rare species. The lack of a comprehensive approach, coherent activities, and effective utilization of national and regional power has hindered efforts to halt the environmental degradation of the Caspian Sea. Negotiations and diplomatic agreements require time to address political obstacles, but protecting the sea and the rights of interested parties should not be subject to legal regime agreements. Coastal governments should recognize their responsibility to protect and exploit the Caspian Sea for present and future generations. The environmental characteristics of the sea also have implications for regional security, necessitating the utilization of national power and international cooperation to ensure stability and protect the water zone. Environmental security is closely tied to human security, as the decline in fish stocks has led to increased unemployment in the fishing industry and has affected shipping companies.

Furthermore, the interlinkage of the water governance of the Caspian Sea with the OECD water governance principles provides a pinnacle for policymakers to assess the gaps and formulation of amendments in the existing mechanisms. The paper highlights the need for effective science–policy interaction in water governance, emphasizing the importance of testing the "science-to-policy hypothesis" at each step to ensure its acceptance and functionality. It discusses the evolving role of scientists in decision-making processes, the involvement of diverse stakeholders, and the challenges of integrating different types of knowledge, including traditional knowledge systems. Emphasis should be given to the importance of establishing relationships, sharing problem framing, and engaging policymakers and other stakeholders in the knowledge generation process. It also highlights the need to institutionalize agreements through robust legislation and address collective action issues in water governance. Coastal landscape planning and promoting nature-based solutions can aid in appropriately allocating human activities, sustainable tourism development, and combating water pollution in the Caspian Sea. Additionally, addressing water level changes and flood events is highly significant to protect coastal communities. Overall, collaborative efforts, comprehensive knowledge integration, and nature-based solutions are essential for effective water governance in the Caspian Sea region.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

Literature review, theoretical development, analysis and interpretation of research studies, writing - original draft, writing - review & editing, and critical revision: Apoorva BAMAL; writing - original draft and writing - review & editing: Sogol MORADIAN; Conceptualization, design, and data analysis: Ali TORABI-HAGHHIGHI; writing - review & editing and supervision: Agnieszka INDIANA-OLBERT.

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